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THE MINERAL RESOURCES OF CHINA. (1919)

PART I. INTRODUCTION

Chapter I. Principles of economic geology.

Not specifically related to China.

Chapter II. Geology of China.

Ore deposit is related to geology at every step. Although the distribution of the mineral resources of a country appears to follow no fixed law, yet on closer investigation there is found to be a definite arrangement. Hence in order to study China's mineral resources it is first necessary to know something about the geology of the country. This is not the place for a detailed discussion of this subject; all that we need is a broad view in order to give us a general idea of our pathway. We shall look at it in this order: (1) Stratigraphical divisions as certified by (those who have studied) the different geological ages, in order to clarify the connection between the ore deposits and these geological ages. (2) Classification and distribution of the igneous rocks, in order to show the relationship between the metallic ores and the mother magma. 3. A summary of the geological history of the country.

1. Stratigraphic divisions. There are numerous similarities and differences between the geology of China and that of other countries being of vast extent it is possible to divide the country into many regions each of which possesses special characteristics. In general the land formations of the N.E. provinces are the most ancient, while in the S.W. the sea remained for a relatively long time and the most recent changes took place there. By the main geological periods we have:

(1) The Archean Group - the earliest strata, of an age almost impossible to calculate, seeing that where outcrops occur observation of the ridges is possible, but not of the troughs. Of the rock the chief is gneiss, with granite next, followed by different kinds of crystalline schist. The granite is extremely hard and weathers very slowly; so that if gneiss is predominant where Archean rocks are exposed, the hillsides will crumble and be slowly lowered, whereas if granite and gneiss-granite rocks are in the majority, there are lofty and steeply rising peaks, as Tai Shan in Shantung and Huo Shan in Shansi, which belong to this class. This group occurs in the north-east, chiefly in Fengtien, Chihli, Shantung, Shansi and Honan; and gneiss and granite are very widely spread in the south, as in the Kwangtung coastal belt, in Fukien and Kiangsi, and in the great ranges of snow-covered mountains in N.W. Szechwan. The granite and gneiss found so abundantly in the CH'IN-LING, FU-NIU and HUAI-YANG Ranges may also belong to the Archean Group. Of ore deposits in this group, gold is the most important in the north; it occurs mostly in gneiss rock in Heilungkiang, Kirin, Fengtien and Shantung. Next comes iron ore in a belt stretching from the south of Fengtien to YUNG-P'ING in Chihli, where there are seams of magnetite and hematite between gneiss and quartzite. Thirdly, there are ores containing copper, and the following places have been famed as copper-producing districts from olden times: WEN-HSI, YUAN-CH'U, CHIANG-HSIEN and HSIA-HSIEN in south-western Shansi; CHEN-AN in southern Shensi; and the YUN-YANG, CHU-SHAN region in north-western Hupeh. The occurrence of iron ores may perhaps be accounted for by the presence in the primitive aqueous rocks of much elementary iron, which through later metamorphic changes became crystalline, forming seams of magnetite. It is observed that this occurs alongside quartzite, the strata being seen together in fixed positions. How is it that gold and copper are found in these ancient strata? It may be that having been deep down in the



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earth they were affected by long immersion in solvents and gases found in the magma, giving rise to the traces frequently found.

(ii) The Proterozoic or Pre-Cambrian Group - there has been a high degree of metamorphism in the strata of this group, and they are frequently hard to distinguish from the Archean; the only certainties are that they contain no fossils and are hence pre-Cambrian, metamorphism is not at all clear and they fall within the scope of the Proterozoic Group. In China this group has been studied with most care in the north, where it is found that it is broadly divisible into two parts with no conformity. (a) The lower section, called the WU-T'AI System, has for its chief constituents gneiss, crystalline schist, marble, quartzite, and chlorite schist. It is most abundant near WU-T'AI-SHAN in Shansi, and there may be further subdivided into the SHIH-TSUI, the MAN-T'AI, and the HSI-T'AI series, with mutual discordancy. It is found extensively also in Chihli, Jehol, and through to the south of Fengtien and the east of Shantung. Below the Wu-t'ai System are located gneiss and crystalline schist rocks among which are useful minerals substantially the same as are in the Archean Group: gold, iron and copper are the most important, and other elements such as lead, zinc, molybdenum and tungsten are met with here and there, with silver-lead ore occupying a comparatively important position. There is much marble in the upper portion of the Wu-t'ai System; magnesium enters largely into its composition, this giving rise to dolomite, periclase, talc and asbestos. Dolomite and periclase have recently been mined in large quantity in KAI-P'ING, FU-HSIEN, CHAO-TUNG and HAI-CH'ENG in southern Fengtien, while talc and asbestos are particularly widely spread through Fengtien, Chihli, Shansi and Jehol. Graphite is another product found in the Wu-t'ai System, but not much of this has yet been discovered. (b) The upper section of the Pre-Cambrian Group is called the MAN-K'OU (or the HO-T'AO) System. Outcrops of this are seen in Jehol, Chihli, Shansi and Honan. The thickness of the strata greatly diminishes when they reach Shantung, so that at times they cannot be found at all. The rocks in the lower section are quartz and sandstone, or shale; in the upper section, limestone containing flint, and the two sections are mutually concordant. Metamorphism of the rocks has not extended far, and there is hardly any difference between them and the Paleozoic strata, only there are absolutely no traces of fossils to be found. Seams of colitic hematite are found between quartzite and limestone in the LUNG-KUEN, HSUAN-HUA region of Chihli. Only the north-eastern provinces have been spoken of so far. In the south the phyllite rock system is well developed in Hunan, Kiangsi and south Anhwei; where it is found in the POU-LIANG WAN-JEN region of Kiangsi it is called the CHING-TE-CHEN system, and where found between the southern side of HSING-SHAN and HUI-CHOU (T.N.; now HSI-HSIEN) in Anhwei it is known as the HO-LING system. The famous China clay (kaolin) of HSING-TZU, POU-LIANG and AN-JEN in Kiangsi is apparently produced in these strata. Sometimes rich gold-bearing quartz veins are present in phyllite rock, as at P'ING-CHIANG in Hunan. But it is generally found that the phyllite age is not completely Pre-Cambrian; metamorphism has taken place by contact with intrusive granite, as with the LU-SHAN schist in Kiangsi.

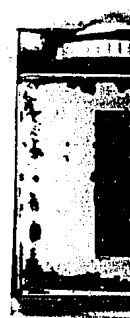
(iii)(c) The lower Paleozoic Group, i.e. Cambrian and Ordovician periods, (alternatively known as the Siniian System, though sometimes this name includes also the upper section of the Pre-Cambrian Group, or is extended to cover the middle Paleozoic period, making it too broad). At that time the ocean waters were advancing and deepening over the whole of



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China, with sedimentation of shale and limestone strata over the Archean or Pre-Cambrian, showing unconformity. Such stratification is found in Chihli, Shantung, Shansi and Honan, where, broadly, a triple division is possible: (a) 'Broad shale', the lowest section, the main rock here being red shale from 30 or 40 to 150 metres thick (b) Above this is 'Howloon' limestone, much of which is oolitic and pschittic limestone (popularly called variegated marble), the thickness of which is from 200 to over 300 metres. In these two Cambrian strata trilobite fossils are extremely numerous. (c) The upper layer is the Ordovician 'Tsingan' limestone, pure and containing few fossils, and from 600 to over 1000 metres thick. The rock used for burning lime in the N.E. provinces is all taken from this layer, for because of its purity and thickness other limestone cannot approach it. The 'CHI-HSIN' Corporation at LUAN-HSIAN (T.H. This is the location of the KAILAN Mines) finds it most suitable for cement manufacture. No detailed study of the lower Paleozoic Group in the S.E. provinces has yet been made; only it is known that there are Ordovician fossils in the limestone of LUAN-SHAN near Hankow, and that where the provincial boundaries of Hupoh, Shensi and Szechwan meet the lower Paleozoic Group is composed of thick limestone strata. The general term for this rock is CHI-HSIN-LING limestone, and the period is shown by the presence of trilobite and brachiopod fossils; it is well over 1000 metres in total thickness, and below it 'broad shale' is absent, being replaced by 30 or more metres of quartz-sandstone and conglomerate made of dense sand and large pebbles, the markings on these showing that they are glacial remains. This is called the NAN-T'AO glacial rock strata, and it is found all the way from Ichang, Hupoh, to the Hunan-Kweichow border region, showing that there were glaciers here at the end of the end of the Pre-Cambrian and the early part of the Cambrian periods, and making it one of the oldest glacier areas in the world. Cambrian fossils in the east of Yunnan are similar to those in Shantung; the rock is mostly yellowish-green shale and sand-shale, and reaches a thickness of over 1000 metres between CH'EN-SHUI and I-LIANG. Marl and sandstone are the chief constituents of Ordovician rocks; they contain the earliest fish fossils.

(iii)(b) The middle Paleozoic Group, i.e. Silurian (or Gothlandian) and Devonian periods. At this time the conditions in the different parts of China were in sharp contrast to one another, but in the N.E. provinces the traces left in even the best-developed lower Paleozoic strata are so vague that we have no means of investigating them; it is only west of Shensi, in Kansu and Sinkiang, that the Devonian are well developed, forming thick limestone strata, and standard brachiopod fossils occur along the T'AIEN-SHAN South Road and on the Shensi-Kansu border. In the river valleys, south of the CH'IN-LING mountains where investigations have been carried on, viz: TAI-NING-HO (Sze), YU-TAI-HO (Shc.), PAI-SHUI-HO (Kan. - Sze), the strata of the middle Paleozoic Group are perfect; below are the Ordovician, above are the Carboniferous, all beautifully concordant. Continuing on above the CHI-HSIN-LING limestone is green shale containing lumps of grey iron, followed by a layer of siliceous rock four or five feet thick which may be called a transitional stratum. On top of it is grey limestone to a thickness of over 60 metres, and green iron-and-coal-bearing shale to a thickness of over 500 metres containing thin seams of crystalline schistose limestone. Anthozoa and brachiopod fossils have been obtained between NING-CH'ILING and KUANG-YUAN; they are covered by more thick limestone strata, blue or grey in colour and with numerous fossils, belonging to the Devonian period. Silurian rock in Yunnan is mostly arenaceous shale with thin limestone strata, not more than 100-200 metres thick, embedded in it. The lower Devonian



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also is still made up of arenaceous shale and marl; when we reach the middle Devonian period limestone is much more abundant, and in it are many anthozoa and brachiopod fossils. Eastward to Kweichow, and Kwangsi, and even to south-west Hunan, the fact that there still middle and upper Devonian limestone can be taken as sure evidence. To sum up, it may be taken as a proved and settled fact that there are extensive and thick strata of Devonian limestone in the western part of China, and all through it mineral traces are to be found, as e.g. copper in Yunnan and mercury in Kweichow, though it is true that these usually occur only in country rock which has entered by filling or replacement, and perhaps has no direct connection with the period.

No detailed study of the middle Paleozoic group has been made in the S.E. provinces; but in the limestones at LU-SHAN Hanking, there are graptolite fossils of the Silurian period, with quartz-sandstone above in which fossils are absent; and this same type of quartz-sandstone is found beneath lower Carboniferous limestone at CHI-HSIA-SHAN, so that it is natural to say that it belongs to the Devonian period. It is called Hanking limestone, and traces of it are found here and there in the provinces of Anhwei, Kiangsi, Kiangsu and Chekiang; at times large lumps of iron oxide are found in it, but there have been no reports yet of any considerable deposits of ore.

(iii)(c) The upper Paleozoic Group, i.e. Carboniferous and Permian periods. Since these were the periods of coal formation, it goes without saying that they are most important. The character of the rocks varies in different places: in the north-eastern provinces the Carboniferous - Permian limestone has a thickness of only a few tens of metres whether in a single stratum or in a number of strata, and it thins out to nothing. In what there is (of this period) sandstone, shale, clay strata and coal beds predominate, and there are many useful minerals apart from coal. Much of the clay can be used as a raw material for the porcelain and pottery industries, explaining the presence of these industries in the coal areas of the north, and explaining too the place-names "TZ'U-HSIEN" (Porcelain County) and "TZ'U-YAO" (Pottery Kila) - these can be taken as showing that coal is produced locally. Then there are ferruginous strata: beds of hematite and limonite are found in the lower section of the Carboniferous system, perhaps contact strata between the Carboniferous and the Ordovician limestone. The ore for native iron industry comes from these. Mining is in a particularly flourishing condition in P'ING-TING, LU-AN and CHE-CHOU, Shensi: it is estimated that the reserves of ore there are sufficient to supply the world's needs for several thousand years, which is perhaps a little extravagant, but still its wide distribution is truly amazing. Pyrite is found both above and below the coal beds, from which sulphur can be obtained by smelting, and from which, by either natural or artificial processes, iron sulphate may be produced, and then vitriols from this. Much pyrite is mined in the Taiyuan region of Shensi. The total thickness of Carboniferous - Permian strata in the north-eastern provinces is only 200-300 metres, but there are quite a number of useful minerals in them which are mutually dependent in their (industrial) application; in either the preceding Sinian system or the succeeding Mesozoic group, mineral deposits, whether abundant or meagre, are intermittent. Limestone reaching a thickness of over 1000 metres is the principal rock in the Carboniferous - Permian system of the region south of the CHI'IN-LING to the Yangtze; two or three times we find embedded in it coal measures formed of arenaceous shale and coal seams, the limestone enclosing it both above and below. This particular stratum of Carboniferous limestone is known both as CHI-T'OU limestone and as WU-SHAN limestone; it

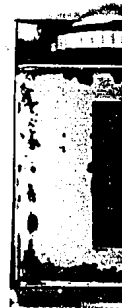


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contains many antholite, brachiopod and spirifer fossils. It is only in Hunan that ferruginous strata, easily worked, are found in the coal measures, with manganese ore plentiful not far away. What has been discovered in Kwangtung and Kwangsi is also good. In Yunnan, limestone containing brachiopod and spirifer fossils is the chief rock stratum of the Carboniferous and Permian systems, except where lower Carboniferous sandstone and middle Carboniferous (upper section) coal measures occur. Now the earth's crust was changing in upper Permian times and volcanoes belched out lava forming tremendously thick beds. This lava was diabase in type; below was thick limestone, and above conglomerate and sandstone. It is very widely spread in central and eastern Yunnan, where this basic igneous rock contains copper, concentrated even more by weathering; hence the copper ore of Yunnan is present or absent according to the presence or absence of this rock, except where there have been other causes for its appearance. The copper of the LU-NAN district is a noteworthy example. In addition to this there are mineral beds, ores of copper, lead, tin, zinc and antimony, which were formed by the intrusion of magma or the gushing up of springs of minerals; but since these may have no connection with the age of the country rock, we shall not discuss them here. Concerning the geology of the coal measures we must await the reports of specialists; it cannot/more than touched on here.

(iv)(a) The lower Mesozoic Group, i.e. Triassic and Jurassic periods, and transitional strata between Paleozoic and Mesozoic groups. Now in the geology of China it is not easy to draw a fixed line between the Permian and the Triassic periods; the strata of the time are all land facies, and are mostly sandstone shale and coal seams. In the north, as at TA-T'UNG in Shensi, coal is the only mineral of real importance, except the mineral oil contained in Jurassic sandstone spread north of the Wei R. and west of the Yellow R. in Shensi. This extends west as far as Sinkiang, which is noted for oil production; while in Jehol, too, oil traces are found in strata of the same period. The Mesozoic group is very widespread in the south. It is worthy of notice that the geology of the Szechwan and Shensi basins, though separated by the CH'IN-LING, are somewhat symmetrical. Iron deposits accompany the coal beds of Szechwan, lying beneath them, the conditions being roughly similar to those in the upper Paleozoic strata of Shensi and Hunan. Of particular value are the salt beds and mineral oil found above (the coal); the rock salt of the TZU-LIU-CHING district is a source of wealth such as is rarely found in the world. Then there is promise of much profit to the mining industry in the recently discovered potassium salts and in the coal gas and petroleum which still wait detailed surveys. There is a stratum of red arenaceous shale next above, to which the gypsum of Hupeh and Hunan seems to belong; the best known production centre of this is YING-CH'ENG, Hupeh. From the standpoint of historical geology, after the Jurassic period China's land mass was already firmly established, all inland lakes and shallow seas had re-evaporated and were dried up; it was then that the deposits of gypsum, salt and oil were formed, and after this time had passed no further deposits of these minerals took place.

(iv)(b) and (5). The upper Mesozoic and Cenozoic Groups. The chief strata of this period are laterite, conglomerate, loess and alluvium in the north, and red sandstone, laterite, conglomerate, lake mud and alluvium in the south, and the age being recent, metamorphism is not apparent; nor, for the same reason, does one hear of useful mineral deposits apart from the following: Miocene series coalfields at FU-SHUN, Fengtien; Pliocene series lignite in CH'U-CHING and I-LIANG counties, Yunnan; and the so-called Gobi strata of Sinkiang, which seem to be Tertiary series sandy conglomerate showing unconformity with the strata below, and in which there is usually gold. As



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well as these, in gneiss or granite hill country, the small pieces broken off neighbouring rocks by erosion accumulate in gullies and pools, and when these are washed out by the streams the light and heavy particles get separated; the native gold, magnetite or other hard and heavy minerals that are present form richer pockets as this process continues. The alluvial gold found along the rivers of the three eastern provinces Heilungkiang, Sungkuang and Lin-chi; and the magnetic sand found between Honan and Anhwei and along the Chekiang and Fukien coast, are examples.

2. Igneous rocks. In considering the relationship these bear to ore deposits, the things to be noted are the basicity or acidity of the components, the depth of crystallisation and the nature of the contacts with the country rock, such as we have done before. The trouble is that there is a multitudinous variety of these rocks, and in China very little study has been given to the. Here only a token treatment of their connection with ore deposits will be attempted. From what is known of igneous rocks in China, there are four kinds, now to be briefly described:

(a) Granitic group, i.e. acidic or ^{intermediate} neutral abyssal igneous rocks, as granite, syenite and diorite. These all seem much alike at first glance, but from the point of view of mineral deposits they are certainly different, so that some knowledge of the individual rocks is essential.

Granite: A mixture of three minerals - quartz, orthoclase, and mica or amphibole. It usually forms the greater part of the mass of igneous rocks, but cannot be said to contain many useful minerals. China's great granite masses, as TAI-SHAN (Shantung), HSI-SHAN (Shensi), HUA-SHAN and CH'IF-LING-SHAN (Shensi), SUNG-SHAN and FU-NI-SHAN (Honan), are all Archean granite. LU-SHAN (Kiangsi) and HENG-SHAN (Hunan) granite intruded later than at least a part of the Paleozoic group; no important metallic ores have been reported from the places where its outcrops occur. The granitic magma intruded deep down in the earth's crust, and crystallisation proceeded very slowly; when cooled to 400 or 500 degrees, complete crystallisation began. Hence any metallic substances it had contained were probably either vaporized or liquefied off, condensing outside this mother magma, for metals are extraordinarily scarce even in great granite masses. And yet some minerals of great importance have formed in the granite of China.

(i) The tin ores found near KO-CHIU in south Yunnan; in FU-CH'UAN, Kwangsi; and in the CHIANG-HUA, I-CHANG, KUET-YANG region of Hunan are all related to granite. Cassiterite was formed either in a contact strip between granite and limestone, or right on the extreme edge of the granite, or in some special type of granite, like gneiss or pegmatite granite, or in limestone adjacent to granite; so that there seems to be no doubt at all that granite-forming magma was the source of the tin ores. In CH'EN-HSIEN, JU-CH'ENG and TEU-HSING in the south of Hunan the recently discovered tungsten as well as tin and arsenic, all lie along or are close to the edge of granite. At CH'UNG-I and TA-YU in south Kiangsi, at HUI-YANG in Kwangtung and near HOJIA-PEN in Fukien, where tungsten ores are found, the rocks belong to the same geological group; and still further east, at YUNG-T'AI, Fukien, and CH'ING-T'AI, Chekiang, where there are reports of molybdenum ore, it is the same. From west to east the geology is similar, but the periods of the occurrence of the minerals are not, some being earlier and some later; so that either the constituents of the magma were originally different or the rate of intrusion was different, so that each mineral has its own special area of distribution. Time



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must be allowed before an incontrovertible proof of this is possible, for the periods of this granitic intrusion are not yet known with certainty. There is just this, that the intrusive limestone is mostly Carboniferous or Permian rock, and there are proofs of this everywhere; but there is no certain evidence yet concerning the limestone of the tin mining district of KO-CHIU, Yunnan, whether to say it is Carboniferous or whether to say it is Triassic - probably it would be safe to say that at the earliest it belongs to the end of the Paleozoic era. Now is it that we find none of the tin group of minerals in the granite further north, while it often occurs in the region to the east of KO-CHIU? Is it that the rock formation is different? or is it that the intrusion has occurred at a different period? From what we know as yet there is no certainty about it. It appears as if the nature and quantity and location of mineral matter in the magma had been fixed before intrusion took place and before the rock was formed.

(ii) Although there are no places where minerals are found in the granite itself, yet they are constantly found in the neighbouring pegmatite or in quartz veins. We have already mentioned tin, tungsten and molybdenum; the next most commonly found is gold, though not necessarily in great quantity. There is a good deal of gold produced from quartz veins in various parts of China. It comes in greatest abundance from the Archean group, but is often found also in Paleozoic rock, while quartz lodes can still be found even in Jurassic strata. Examples of this are seen in the Western Hills, Peking. These quartz veins were not necessarily formed very deep down; consequently although the granite crystallized amongst relatively old rock strata, yet the quartz veins are able to penetrate to a long distance above the mother magma. Although there is a most intimate relation between quartz (colloquially called Horse-tooth Stone) and gold, yet it really seems as though the most trustworthy (for the finding of the gold) is that in the nearby pre-Cambrian granite. Gold is not readily fusible, hence there is no great change in location because of fusion - this is a fixed principle. But in quartz lodes of later periods other minerals of great importance, such as copper, lead, zinc and antimony, are common also.

Syenite and Diorite. The chief constituents of syenite are orthoclase and aegirine; in diorite the orthoclase becomes plagioclase - this is the only difference between these two, which are closely related to China's iron ores. Moreover in the mother rock of the latter, orthoclase and plagioclase, no matter in what quantity, are never very easily distinguishable; but as their relationship to the ore is just about the same, there is no real necessity that they should be distinguished. The well known ores, like those at the CHIN-LING-CHEN Iron Mt. (T'IEH SHAN) in LIN-TZU, Shantung; at LI-KUO-I in T'UNG-SHAN, Kiangsu; at SHIH-TZU-SHAN in TA-YEH, Hupeh; at T'IAO-CH'UNG in FAN-CH'ANG, and at T'UNG-KUAN-SHAN in T'UNG-LING, in Anhwei, are all found in syenite or diorite and limestone contact regions. The significance of the location is very evident. Then again special minerals like garnet and epidote occur; and often the limestone is changed to marble: all these provide adequate evidence that the magma was still at a high temperature at the time of its intrusion, and that chemical action took place. The surrounding contact rock seems to have exerted an attraction on the iron through the magma causing its concentration as magnetite, or by further acidification forming hematite. Most of the iron in the Magma was probably basic in character and showed a tendency originally to flow towards the outside;

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it was acted on chemically when it met the surrounding limestone and changed to acidic ore. Iron ores formed by contact metamorphism are also met from time to time in granite, but they are generally less in quantity than those contact ores in syenite and diorite. As to the period of intrusion of the syenite or diorite that forms the mother rock of this class of iron ores, it would be natural to fix it relatively to the rocks into which the intrusion occurred. At TA-YEH, Hupeh, FAN-CH'ANG and T'UNG-LING, Anhwei, the intrusion was into Carboniferous limestone; at LI-KUO-I, Kiangsu, and CHIN-LING-CHEN, Shantung, it was into Ordovician limestone. It looks as if the southern intrusion was the later, and the northern intrusion the earlier, but in fact that is not the case. Of northern limestone, that of the Ordovician period is the most widespread, hence contact iron ores were formed in it, though the period of their formation was still really post-Carboniferous. The most satisfactory proof of this statement is the diorite of WU-AN county, Honan, such as at the HUNG-SHAN mines and other places; both diorite and contact iron ore are in Ordovician sandstone, whereas at SHANG-CH'UAN-F'U nearby there are intrusive dykes of diorite right in Carboniferous coal measures. It will be seen from this that although the northern and the southern iron deposits are well separated, yet they were formed from similar types of magma, probably, which intruded at the same time. The period of this intrusion was, at the earliest, post-Carboniferous; its geographical distribution was not limited, apparently, to any fixed district. Just why the magma of the period should contain so much iron is a problem in petrography. Other metals sometimes occur in syenite contacts, e.g. copper at YANG-HSIN, Hupeh; zinc and lead at SHUI-K'OU-SHAN in CH'ANG-NING (county), Hunan; zinc at KAO-TU-K'ENG in CHU-CHI (county), Chekiang; but there are also differences between them. The formative cause of the copper ore is probably the same as of the magnetite, given above; in the case of the lead and zinc ores the country rock is on the whole devoid of any traces of contact metamorphism, and in particular (?) garnet is not found para-genetic with them, so although the ores are located in contact belts, yet their formation was purely by means of precipitation after fusion, and so a little different from the magnetite and other iron ores.

(b) Porphyritic group, i.e. acidic, porphyritic, igneous rocks. Intermediate rocks such as andesite, and other dike-forming intrusive rocks, when they occur in China have generally very little connection with metallic ore deposits; but the actual amount of them is small, and the area of distribution is less than that of the acidic, porphyritic rocks. These latter are extremely complex in nature. The most common is quartz-porphyry, with quartz as phenocrysts, and with microclitic quartz and orthoclase or semi-crystalline or glassy silicates as groundmass. At times there is very little quartz, while the feldspar phenocrysts are extremely numerous, and it is then called orthophyre. The two sorts are constantly found side by side, and trachyte, rhyolite or some andesite may be found scattered amongst them. The places of widest distribution, as far as is now known, are north-west CHIHLEI and central HONAN in N. China, and CHEKIANG and FUKIEN in S. China. The rocks are very dissimilar in the two areas. Most of the northern porphyritic rocks are volcanic in origin; those in the south (still waiting detailed study) appear to belong to the intrusive group. At MOKAN-SHAN and TIEN-MU-SHAN, Chekiang, the quartz-porphyry groundmass is entirely crystalline - if this may be taken as typical. But on the other hand the indications of flow

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which appear in the quartz-porphyry of the OU-CHIANG basin, Chekiang, make it seem quite certain that it is eruptive in character. To change now to the discussion of periods, the porphyritic rocks of central Honan belong to the Proterozoic group, the strata, at MEIN-CH'IH and LU-SHAN, being constantly beneath NAN-K'OU system sandstone, or formed between the lower layers of the sandstone: the sequence seems to leave no room for doubt. As to north-west CHIH-LI, the indications as observed at the Western Hills, Peking, and in the vicinity of HSUAN-HUA show that the extrusion occurred at the earliest at the end of, or later than, the Jurassic period. The porphyritic rocks of Fukien, Chekiang, Kiangsi and Anhwei have not yet been studied in detail as to period, but it is a fact that in Chekiang some extend right in amongst the Palaeozoic group.

In this porphyritic group of rocks, as in N.W. Chihli, a little copper ore, but only very little is sometimes found. In Chekiang and Fukien infiltration of lead, zinc, silver and copper in the form of veins constantly appear and disappear, uncertainly, with the dike-rock mostly quartz. From examination of the structure of this group of ores it appears that they have been formed by precipitation after flowing into the fissures while the ores were in a molten condition. They seem to have an intimate connection with the magma of the porphyritic rock. Of metalloids, the majority are produced in quartz veins through porphyritic rock, an example being the fluorapatite of HSIN-CH'UNG and CH'ENG-HSIEN, Chekiang. It is very probable that after the porphyritic rock was formed the gaseous or dissolved elements still remaining in the magma continued to percolate out and filled up the fissures which had already made their appearance (in the main mass of rock). Another example is the (alumstone or ? vitriol), one of China's important mineral products, which occurs along the Chekiang-Fukien border, certainly in rocks of the porphyritic group. The potassium and aluminium (ores) contained in orthoclase and other rock minerals have been formed through changes brought about by erosion with sulphuric acid solution.

(c). Diabasic group. In this group there are differences of coarse and fine, of deep and shallow. Deep intruded, coarse grained crystalline rock is called gabbro. It is found, usually in small volume, in most places and belonging to all periods; and ore deposits are found connected with it, as e.g. copper at HUI-LI in Szechwan, and at HSUAN-WEI in Kweichow, where this group of rocks may be connected with its formation. The copper is limited to a small area. (T.N. HSUAN-WEI lies in Yunnan. Copper is found in the Kweichow county of WEI-NING which adjoins HSUAN-WEI on the north). The group occurs very widely: the fine-grained diabase of eastern Yunnan, beginning at the Yangtze on the north extends south to CHIEN-SHUI, and from TA-LI on the west to TUNG-CH'UAN (now HUI-CHIE) on the east, its traces being seen everywhere, though the outcrops are particularly numerous between CHAO-T'UNG and TUNG-CH'UAN and then between HSIN-TIEN and LU-NAN. A part of this class of rock is either diabase-porphyrite or andesite, the difference being seen by the structural composition. Generally it may be said that the two chief components are always pyroxene and plagioclase, and that the former crystallized in the ground-mass after the latter. This is the special characteristic of diabase. Phenocrysts may be few or many, and indeed this is of no great significance. If there are no feldspar phenocrysts the porphyritic structure is not clear and in the past it was mistaken for basalt, but in reality olivine is lacking among the mineral constituents, and in the main it



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can be safely reckoned as diagenetic. Rock flows of great thickness were formed volcanically during the Permian period, and wherever out-crops of these occur copper ores are found. Richer collections of native copper have been effected by secondary surface action, though the size of these deposits is not usually as great as those formed by displacement or fissure filling. Because of the number and the wide extent of the ore deposits, vestiges of old minerals are always found with them, and cobalt and nickel tend to appear irregularly. The cobalt ores of Yunnan are cobalt-manganese substances which have been acted on by acid or acid and water and then enriched by secondary action.

(d) Peridotite and basalt group. The rock known as peridotite is deeply intruded, alkaline, and the strongest of igneous rocks, having olivine as its chief mineral component, then pyroxene and a small amount of feldspar. Basalt was formed by volcanic eruption or shallow intrusion; its rock-forming minerals and groundmass structure are such the same as for diabase, and again olivine is its chief component. Let us now consider them separately:-

Peridotite. This is found at CH'ING-K'UANG-SHAN in HUI-LI county, Szechwan (T.N. HUI-LI is now in the southern part of the Szechwan province). Apart from olivine it contains diopside (or malacolite) and nickel-bearing pyrite, the amount of nickel usually averaging 2 to 3 % of the whole. Peridotite has been discovered also near HSIN-T'AI in Shantung; here it contains pyroxene and small quantities of chromite. Generally speaking, although China has not yet discovered those minerals such as cobalt, nickel, chromium and manganese (which are usually associated with alkaline rocks) in large enough quantities to make their exploitation profitable, still there are evidences of them; and in the matter of the implications of their paragenesis it is hard after all to escape from the common laws of economic geology.

Basalt. Basalt of every period is often seen, but that found in China is mainly limited to the Tertiary and Quaternary periods. There is a wide distribution of basalt lava over the Mongolian plateau in the north, and about P'U-K'OU on the border region between Kiangsu and Anhwei in the south; while volcanic traces exist noticeably at T'ENG-YUEH and T'AI-YIN-SHAN in Yunnan. But no traces of ore deposits have been found in the basalt. Regarding the period of its extrusion, basalt has been found above loess at T'AI-AN, Honan, and at H'UEH-HUA-SHAN, CHING-HSING, Chihli; the underlying loess shows some little trace of metamorphism. Hence the period of its extrusion, at the latest, would be the end of the Pliocene epoch of the Tertiary period. But theoretically it is not necessary to suppose that the eruptions of basalt took place everywhere at the same time. Between FENG-CHEN and TA-T'UNG in Shansi basalt covers the highlands and is found on the plain, while to the N.W. of TA-T'UNG there are high overhanging mountain ridges of conglomerate which contains lumps and pebbles of basalt in it, so that it seems that the basalt there must have been erupted before the topography of the present era took shape.

3. Geologic History (or Structural History)

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(Mineral Resources of China, 1919. Chap.II)
contd3. Geologic History (or Structural History).

There are two kinds of movements in the earth's crust. In one, folds, creases, faults and fissures in the strata are caused by transmission of lateral pressure; this in geology is called Orogenic movement. In the other, pressure is transmitted in a vertical direction, resulting in strata being raised or lowered, showing breaks without such folding; this is known as Epierogenic movement. Changes through movements in the earth's crust have occurred from time to time all through the ages, with formation or destruction of ore deposits accompanying them. Now every time such a change occurs some of the rock strata must be altered by folding; or if no folding occurs there is some subsidence after breaking, and the lower the strata sink the easier it is for magma to penetrate, and so the ore deposits formed will be the more numerous. Those which have come into the folds or the sunken strata become exposed when another movement takes place, and can see them as valuable deposits to be mined. Although these changes in the crust begin and end very gradually, yet they seem to occur most plentifully in isolated periods, outside of which the crust is quiet. Moreover the newly formed strata lie mutually parallel, while those belonging to earlier or later periods do not as a rule show this parallelism: even if some do, there are certain to be others which do not. The general term for this last is "Unconformity" or "discordancy". Not only is the structure different above and below a discordant stratum, but the ore deposits are changed too; and this is the reason why it is essential for mineralogists to know something of Geologic History. The greatest movements in China's geological history may be listed as follows:-

(a) Between the Archeozoic and the Proterozoic eras.

The unconformity between Archeozoic and Proterozoic groups has already been spoken of; the rocks and minerals are very dissimilar. Much granite is found in the Archeozoic group, but not later; pegmatic granite and quartz veins intersect in all directions almost everywhere, this being the reason why gold is the only mineral found in any quantity. By the end of the Archeozoic era the N.E. part of China had already emerged as dry land, but the waters of the sea encroached during early Proterozoic times and the thick strata of the Wu-t'ai system were formed. (There may have been diastrophic changes several times during this period). Archeozoic rocks directly underlie those of the Cambrian period all over Liaotung, Shantung and the Mongolian plateau; none of the Proterozoic group lie between. There may have been some of the old land which was not completely submerged, but judging from the extent and depth of metamorphism shown by the Archeozoic group of rocks there must have been diastrophism which took them down very far below the surface. The intrusion of igneous rocks, the metamorphism of aqueous rocks, and the formation of the minerals gold and copper certainly took place at this time. Sinking to such depths meant that other strata covered them above; and today's high mountains outcrops do not really go back so far in geological time. It is likely that the covering strata, after emerging at some later era, has been removed by erosion.

(b) Middle of the Proterozoic Era. The Proterozoic group has not yet been closely studied in the south, and there is still some uncertainty about the Wu-t'ai system in the north, even though it is divisible into strata. There are evidences of unconformity between the Wu-t'ai and Nan-k'ou systems



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which cannot be mistaken; the rocks of the former show, on the whole, exaggerated inclination, inversion and disorder, and contain no lack of both metal and metalloid ores. As soon, however, as the Nan-k'ou system is reached, metamorphism is found to be superficial and the structure simple, and there is no sign of minerals apart from a few places where contact metamorphism has occurred. From this it is apparent that prior to the Nan-k'ou system the part that China now occupies underwent violent changes causing the strata to be metamorphosed by folding; such violent movement is not observed again in China, apart from one or two special areas. These cataclysmic changes were followed by volcanic activity. The profusion of volcanoes at the beginning of the Nan-k'ou period can be visualised by the fact that right through Mien-shih and Lu-shan in Honan porphyric rock flow is found beneath quartz sandstone or stratified alternately with it.

(c) The pre-Cambrian period. In the north-eastern provinces Cambrian strata generally lie parallel with the Nan-k'ou system; and some are directly above the Archean group, being found thus, for example, everywhere on the Shantung peninsula and north of Ch'ang-ch'ang. South of the Yangtze there are very few strata found of which it can be said with certainty that they are Cambrian: only in eastern Yunnan unconformity between Cambrian rocks and the crystalline rocks beneath is clearly seen, and again between Huang-ling gneiss (Archean group) and Cambrian rocks above it, near I-ch'ang, Hupeh. Now we know that in pre-Cambrian times there was a period of import-and changes, the majority, if not all of these being in the nature of land-forming movements; this is the reason why Cambrian and Proterozoic rocks are everywhere parallel to one another. In the places where the rock strata are parallel the degree of metamorphism of the aqueous rocks, the cracked nature of the igneous rocks, and the type and size of the ore deposits are all much the same (in the two groups). In places where the upper Proterozoic group is lacking, the unmetamorphosed Cambrian and the crystalline rocks below are each cut off short at the surface where they meet, and are very easily distinguished.

(d) The middle of the Paleozoic era. North of the Ch'in-ling mountain range and east of the Yellow River, upper Paleozoic directly overlays lower Paleozoic, with no trace of Silurian and Devonian series rocks. Surely then none of these latter could have been deposited there at that period, or if so erosion and wear have been so drastic that they have completely disappeared leaving no trace behind. Those who have investigated the matter in greater detail have come to the general conclusion that an area of present N.E. China was, at the end of the Ordovician period, influenced by the land-forming movement and gradually emerged, existing as a land mass during both Silurian and Devonian periods, while those parts south of the Ch'in-ling mountains and in the N.W. of the country were still under the sea. The water above the N.W. and S.W. provinces was particularly deep, and hence limestone and green shale of great thickness were formed; above the lower Yangtze area, (Kiangsu, Anhwei, Kiangsi and Chekiang), the water was shallower and only sandstone (and conglomerate occur there. Again, in east Yunnan the thickness of Devonian series is not less than 2500 metres, but it is not found at all to the north or northwest of Kun-ming, Cambrian and Ordovician rocks there being covered directly by those of the Carboniferous period. It is the same to the west of Fu-shan and Hsing-yün-hu. So it seems that this area must have emerged about the middle of the Paleozoic era, resulting in the Devonian strata being removed by erosion.



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(e) The Upper Paleozoic era. From China's geological strata it is seen that Mesozoic and Paleozoic rocks have, generally, parallelism and continuity where they meet: there are no signs of interruption between them. But east of Pa-ta-ho in Yunnan many Carboniferous period strata are lacking or incomplete: there are strata of the upper Carboniferous period directly covering lower Carboniferous or (west of Li-le) Devonian strata. At this place traces of diastrophism between middle and upper carboniferous periods are shown, only it is limited to a small part (of the strata). Its scope was more extensive by the end of the carboniferous period or the middle of the Permian period. The land of eastern Yunnan took form by emergence after the middle of the Permian period: volcanic activity was in full blast, and diabasic lava was thick and extensive. This was succeeded by intense erosion, resulting in the formation of sandstone and conglomerate. The Triassic period brought another encroachment by the sea; near Kuan-shan in S. Szechwan, Permian or Triassic limestone has been discovered directly covering Silurian strata, so that it is quite evident that folding and emergence took place there at the end of Paleozoic times. In the other N.E. and S.E. provinces, although strata belonging to the end of the Paleozoic period show no traces of uniformity, yet from observation of the nature of the rock fossils it is seen that the sea waters retreated at that time never to return again since. A great change took place also in the climate, which became dry and cold. In central Shantung there is a great deal of basalt lava in amongst red cross-bedded sandstone, and igneous rock dikes are very often found penetrating right through Carboniferous and Permian systems. It is evident then that there must have been intense volcanic activity in that area at the end of the Paleozoic era. Elsewhere, in places where there has been formation of the diorite and syenite of contact igneous rocks, in the S.W. where the various intrusive igneous rocks are connected with deposits of lead, zinc and copper, and in the south where a belt of granite contains tin and tungsten deposits, in spite of a fully detailed study not being yet available, yet from what we already know it may be inferred that the time of the intrusion does not lie outside of the end of the Paleozoic and the beginning of the Mesozoic era. To sum up, there are some parts of S.W. China which, during the transition period between these two eras, passed through folding, emergence, erosion and re-submergence. There was very little folding apart from this, and emergence of the whole (land-mass) then gradually took place. The interval magma was in a state of great activity, either intruding into the strata or being extended over the surface; and it was in these circumstances that the important mineral deposits were formed, though the phenomena did not necessarily take place simultaneously everywhere. e.g. There is unconformity in Carboniferous period (strata) in central Yunnan which has not yet been heard of elsewhere. It is an undoubted fact that the end of the Paleozoic era is an extremely important period in the Geologic History of China. Again, rock metamorphism goes very deep in the Ch'in-ling mountain range belt, and from examination of the order of the rock strata it looks very much as if many of them belong to the Carboniferous and Permian periods. It is true indeed that the Ch'in-ling belt experienced one most intense fold and metamorphism with intrusion of igneous rock. Now in changes of the same period it frequently happens that if the orogenic movement is the predominating one within one part of a definite area, then the epeirogenic movement is the main one in other parts: the changes in China at the end of the Paleozoic era are an example of this.

(f) The Mesozoic era. At the time of the Triassic period Sinkiang and Kansu in the N.W. and Szechwan, Yunnan and Kwichow in the S.W. were still submerged again under the sea, while the whole of the remaining section along the East was dry land.



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This means that at the beginning of the Mesozoic era Tibet was a great island, sea water extending both north and south of it. From that time forward the water surface gradually narrowed and the land surface increased, with large and small basins remaining where relic seas were located. The most important of these were: in the North, N. Shensi - E. Kansu; in the South, Szechwan. So, although separated by the Chin-ling, these possess remote symmetry. Communication through to the main ocean remained open for a time, but this gradually closed up; the influence of climatic changes was felt, salt beds being formed as the water evaporated, and, at some time, oil-bearing strata also; in places where vegetation had flourished coal seams came into existence. All this was in Jurassic times. The main volcanoes were still erupting at the end of the Jurassic period, there being reliable evidence of this in the Western Hills, Peking, where the intrusive igneous rocks are often seen in dike or stratified formation. But whether the large masses of granite are intrusive or not is still a question, though we can make a reasonable guess. Granite crystals form only at a relatively great depth below the surface, but in the geology of China no important subsidence has occurred since the Jurassic period, so that even if there was intrusion of granite during Jurassic times, yet how improbable it is that it could rise so quickly into Jurassic strata! Hardly any sedimentation took place in China during the Cretaceous period, but the from the close of the Jurassic period there has been a good deal of folding everywhere. It is since then that the wearing down of China to a peneplain has taken place: there has been no great amount of erosion nor yet of sedimentation.

(5) The Cenozoic era. Further movements have arisen in this era, but at different times, and certainly unconnected. The nature of these movements, apart from some local ones, is generally speaking epirogenic, with formation of simple folding and vertical faulting or gentle undulations. But in flexure and faulting of this type the distances and the shifting (of strata) are tremendously great, and result in some of the oldest strata being lifted and emerging, so making the stored-up minerals in them available for mining. There is also plentiful formation of igneous rocks. The topography of the earth as we now know it has been formed during this era.

End of Chapter II.

(Remainder of book not required at present).

